

# Detection of BH Encounter GWs Using BBH Template

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# Outline

BH Encounter

Minke and Vitamin Search

PE Run Using spinning/non-spinning BBH template

# Black Hole Encounter

## GR capture

Place: globular clusters and the centres of galaxies

The energy radiated by GWs  $>$  The initial orbital energy

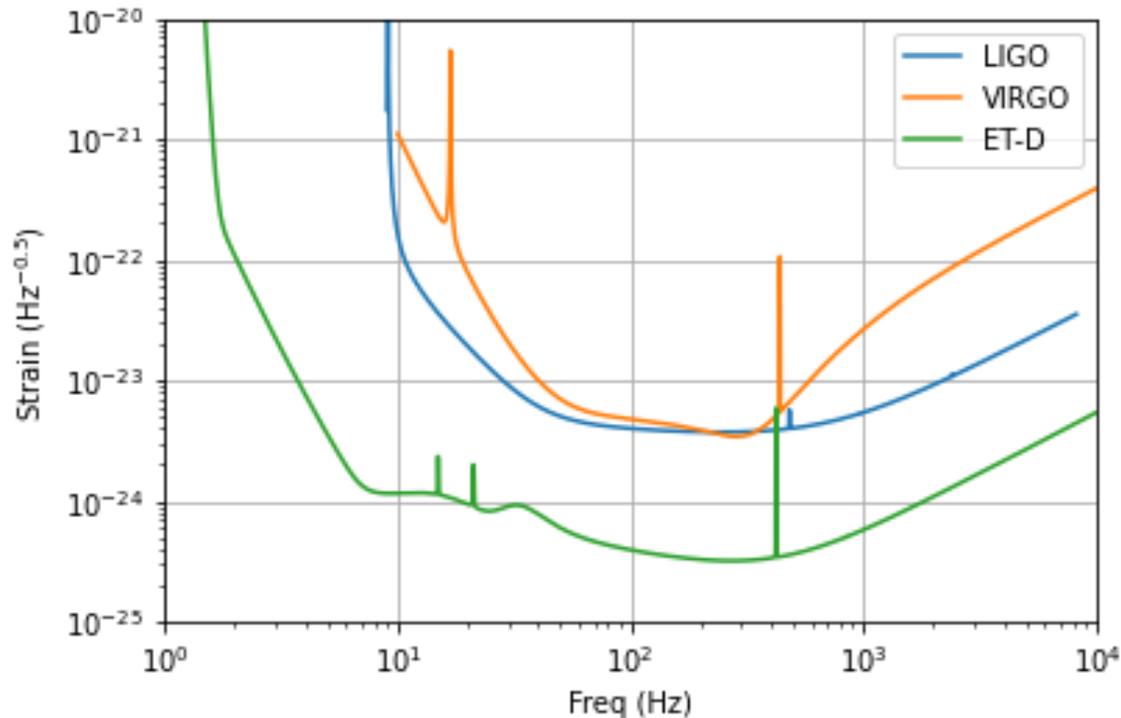


Fig.1 The ASDs of detectors

# BH Encounter

lack of a long  
inspiral phase  High eccentricity

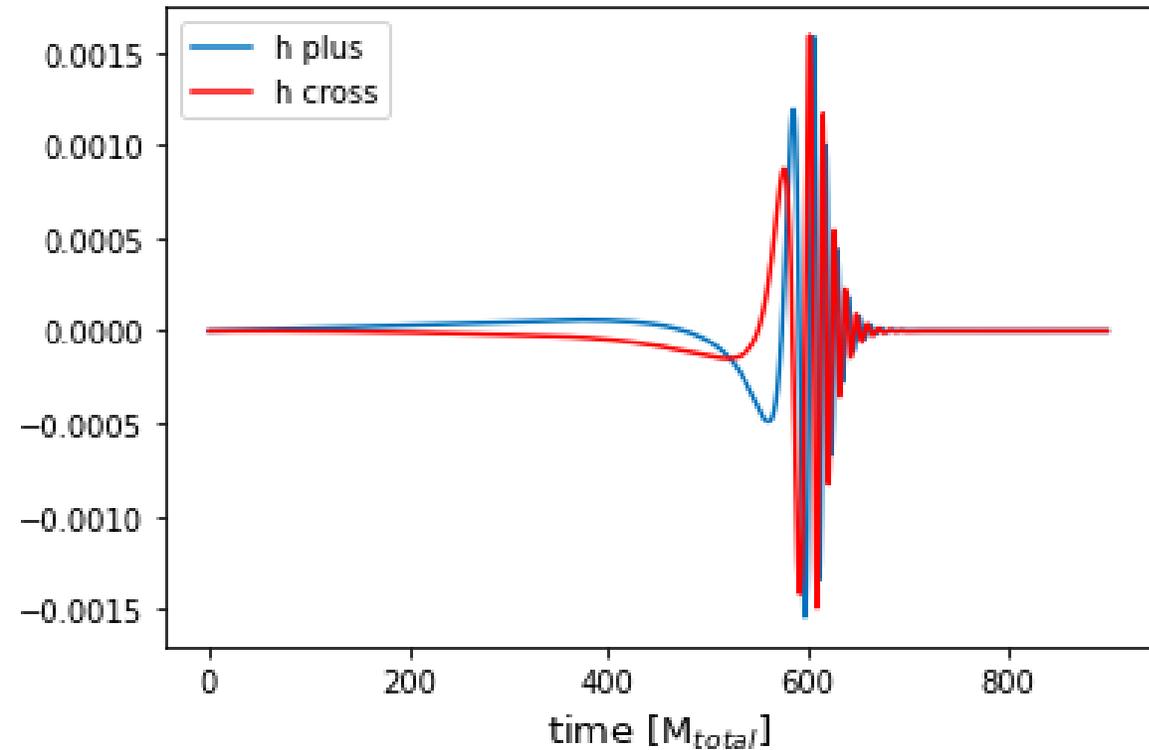


Fig.2 Encounter waveform with mass ratio  $q = 1$

# BBH

inspiral — merger — ringdown



loss of the orbital energies

circularized

4

# Inject BH encounter

Waveforms (2017 Yeong-Bok Bae et. al.)

- Parabolic approximation
- non-spinning pairs of BHs
- relative velocity up to 10 ~ 20 % of  $c$

We pick up the merger ones to mimic BBH.

$$5 \times 100 = 500 !!$$

## The injection parameters

Parameter	min	max	units
$m_{total}$	150		$M_{\odot}$
$d_L$	5,10,15	<sup>a</sup>	Mpc
ra	0	$2\pi$	rad.
dec	$-\pi/2$	$\pi/2$	rad.
$\psi$	0	$2\pi$	rad.

The distributions of locations can be specified by Minke.

The code to inject BH encounter is provided by D.Williams

# Vitamin Search

## The prior of Vitamin

Parameter	min	max	units	prior
$m_{1,2}$	30	160	$M_{\odot}$	uniform
$d_L$	1000	3000	Mpc	uniform
$t_0$	0.15	0.35	seconds	uniform
ra	0	$2\pi$	rad.	uniform
dec	$-\pi/2$	$\pi/2$	rad.	cosine
$\Theta_{jn}$	0	$\pi$	rad.	sine
spins	0	-	-	-
epoch	1126259642	GPS time	-	-
detector network	H1, L1, V1			

The network training is made by H.Gabbard

# Vitamin Search

Find the encounters whose posteriors appear similar to high mass BBH's.

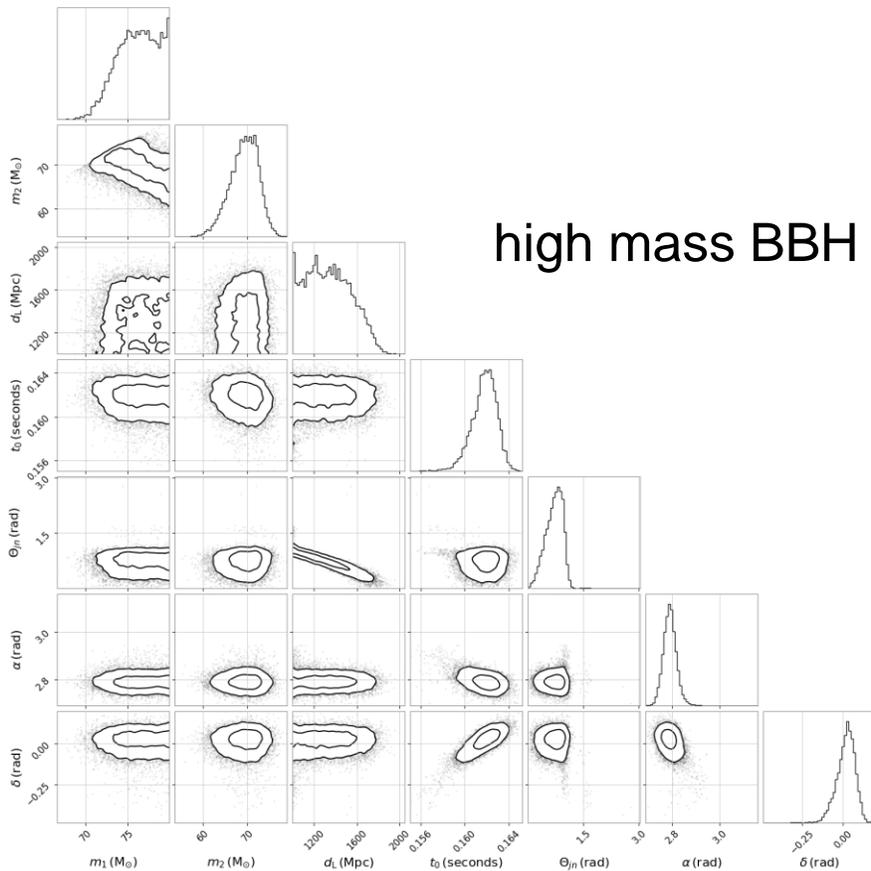


Fig.3 High mass BBH on Vitamin

# non-BBH like posteriors

— No peak or hump

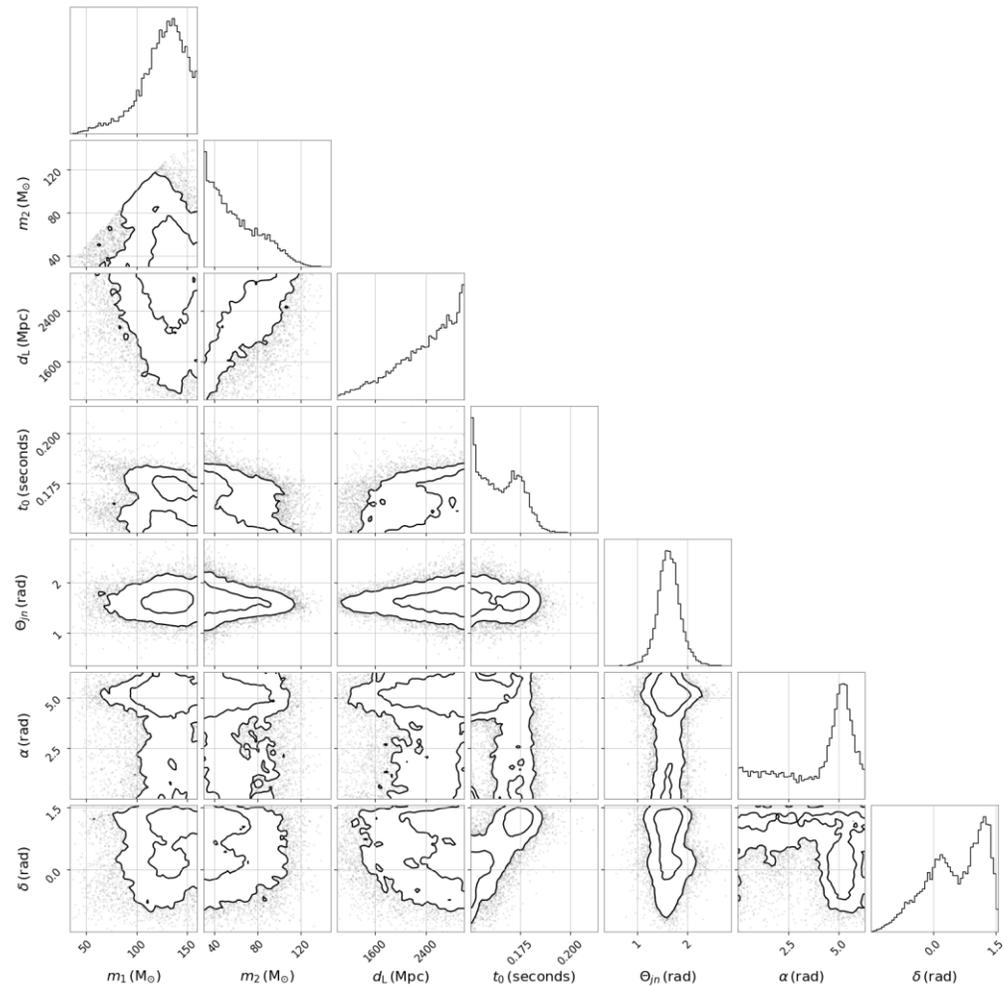
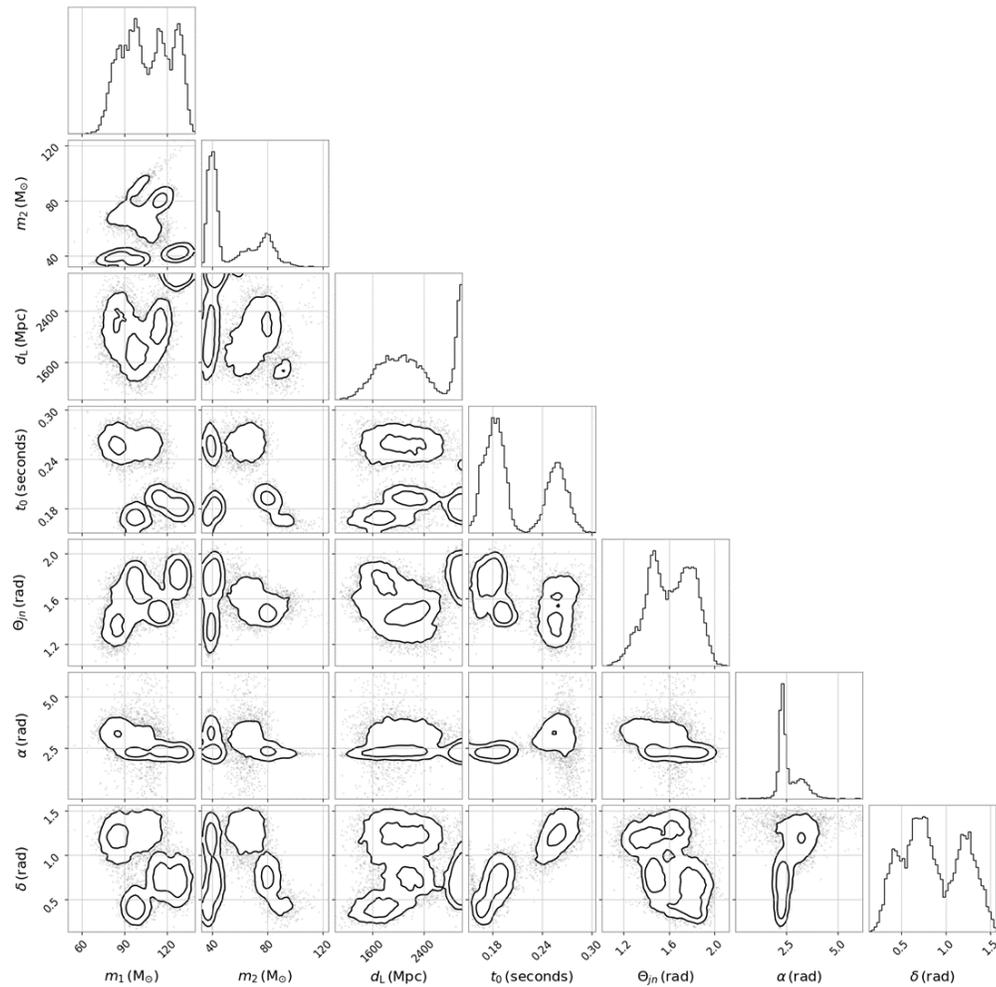


Fig.4 Non-BBH like signal on Vltamin

# BBH like posteriors

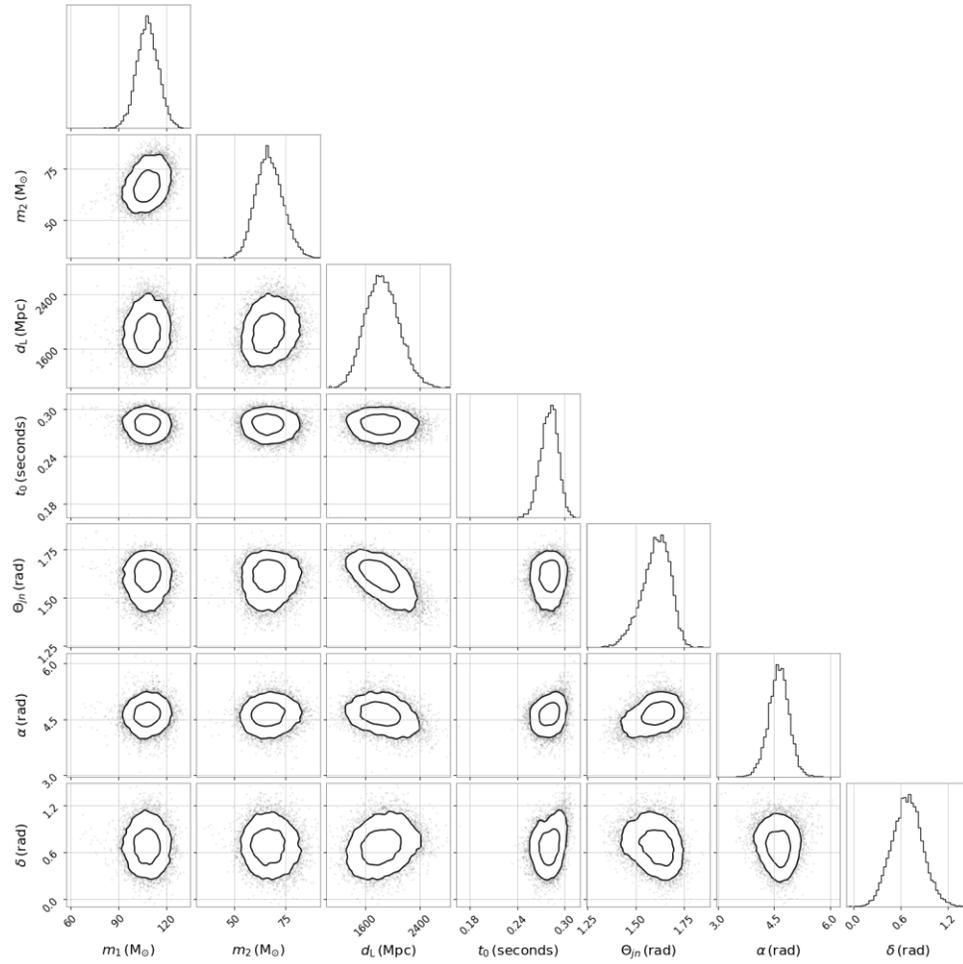


Fig.5 BBH like signal on Vltamin

## BBH like signals

Samples

Mass ratio $q = 1$	$\frac{26}{100}$
Mass ratio $q = 2$	$\frac{14}{100}$
Mass ratio $q = 4$	$\frac{4}{100}$
Mass ratio $q = 8$	$\frac{12}{100}$
Mass ratio $q = 16$	$\frac{17}{100}$

## Injection parameters and optimal SNRs of BH encounter waveforms

No.	mass-ratio $q$	$M_{total}(M_{\odot})$	$d_L(\text{Mpc})$	location(rad.)			$\rho_{opt}$		
				ra	dec	$\psi$	H1	L1	V1
1	1	150	15	2.94	0.84	0.19	5.29	3.43	14.09
2	1	150	15	0.42	-0.53	0.92	5.15	7.13	12.52
3	2	150	10	5.83	-0.04	0.86	11.29	9.54	11.62
4	4	150	5	5.70	-0.44	1.82	9.44	9.57	15.13
5	8	150	5	0.01	0.41	3.03	13.29	11.07	3.85
6	16	150	5	0.01	0.41	3.03	13.29	11.07	3.85

Fig.6  
 Typical BBH posterior using BBH non-spinning model, with time and phase marginalization

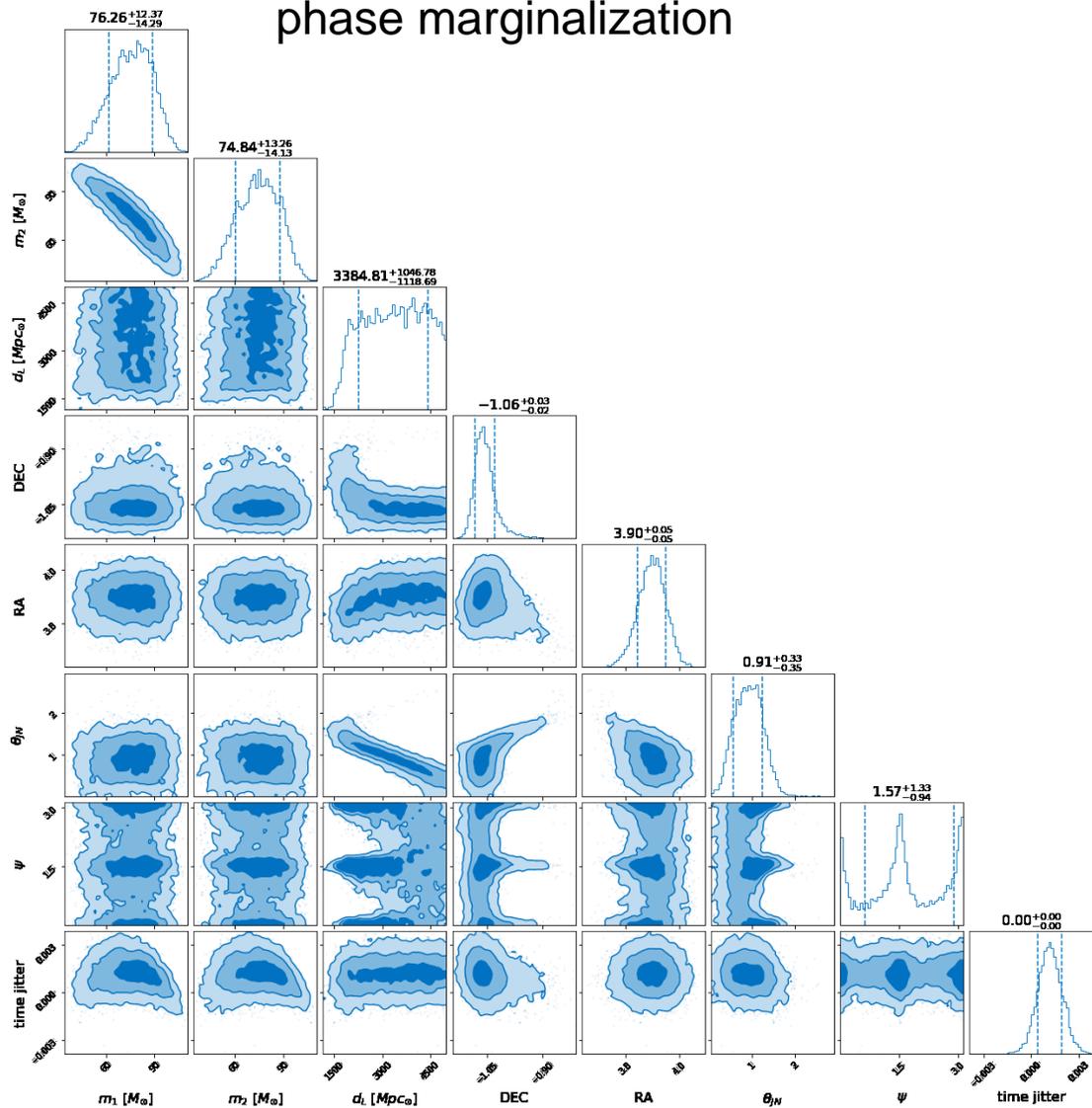
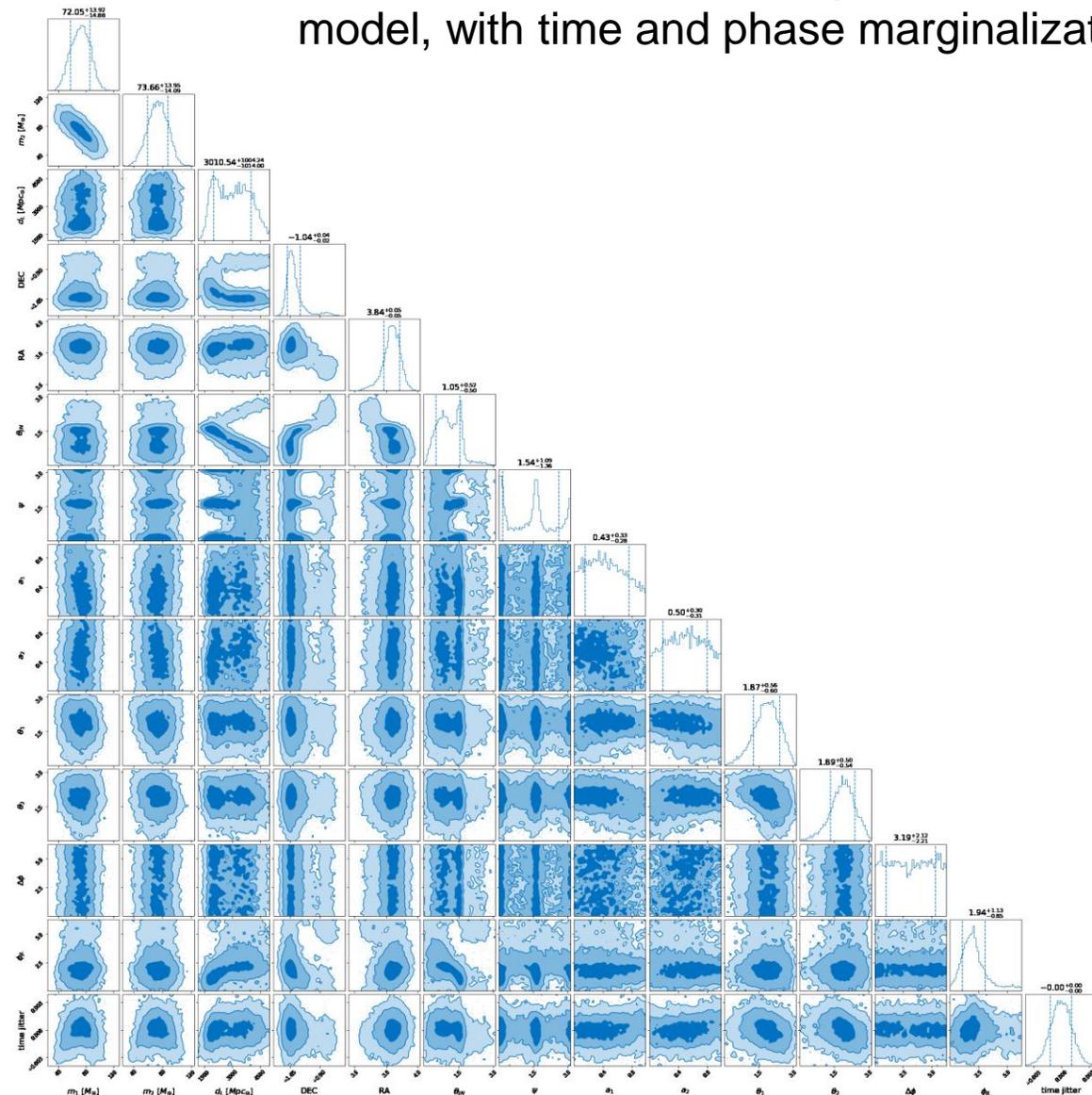


Fig.7  
 Typical BBH posterior using BBH spinning model, with time and phase marginalization



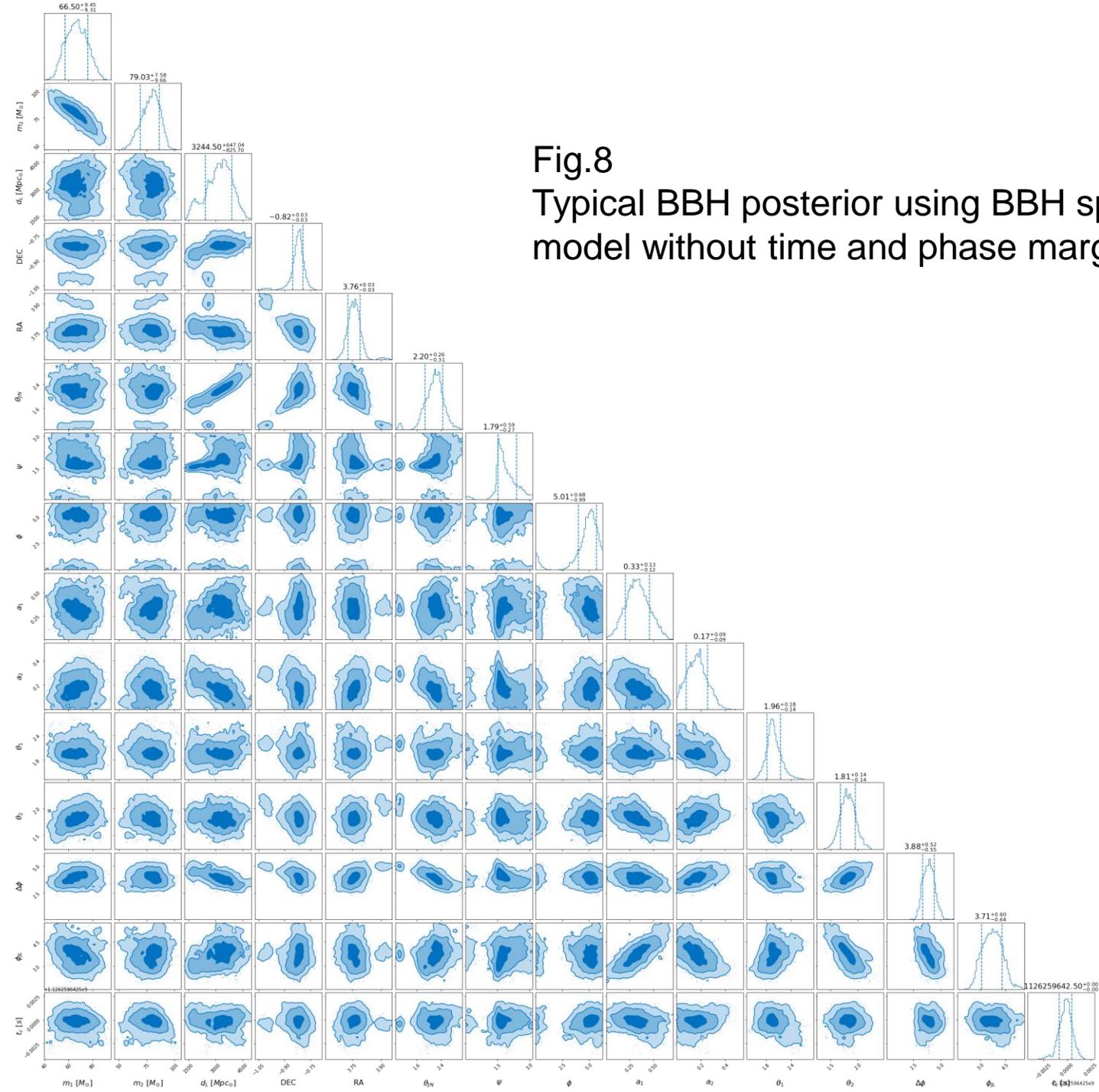


Fig.8  
 Typical BBH posterior using BBH spinning model without time and phase marginalization

Let's see how  
BH encounter  
performs on Bilby !

Signal No.2 (q = 1)  
IMRPheonomPv2, non-spinning

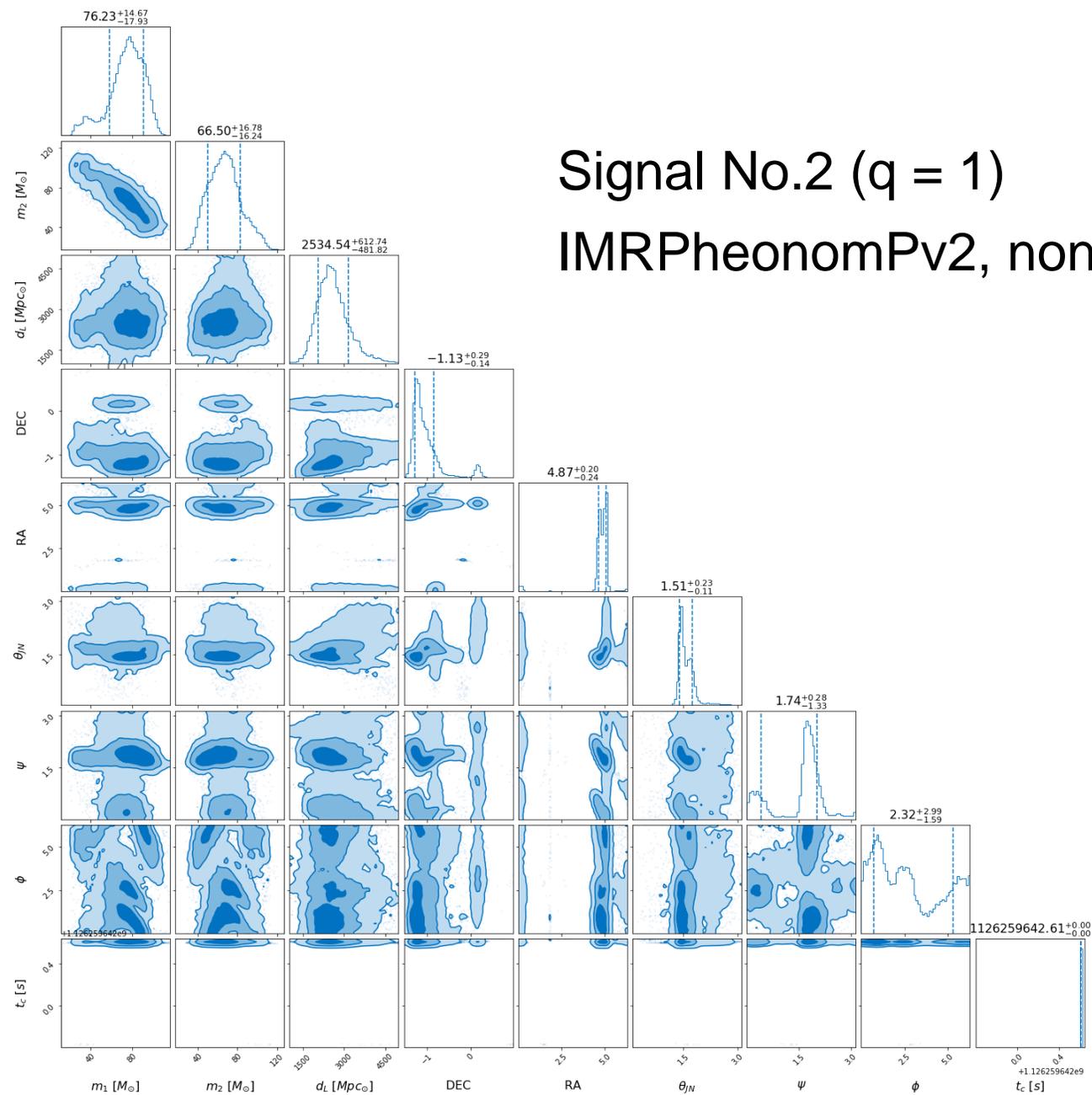


Fig.9 encounter on Bilby with non-spinning model

Signal No.2 (q = 1)

IMRPheonomPv2, spinning

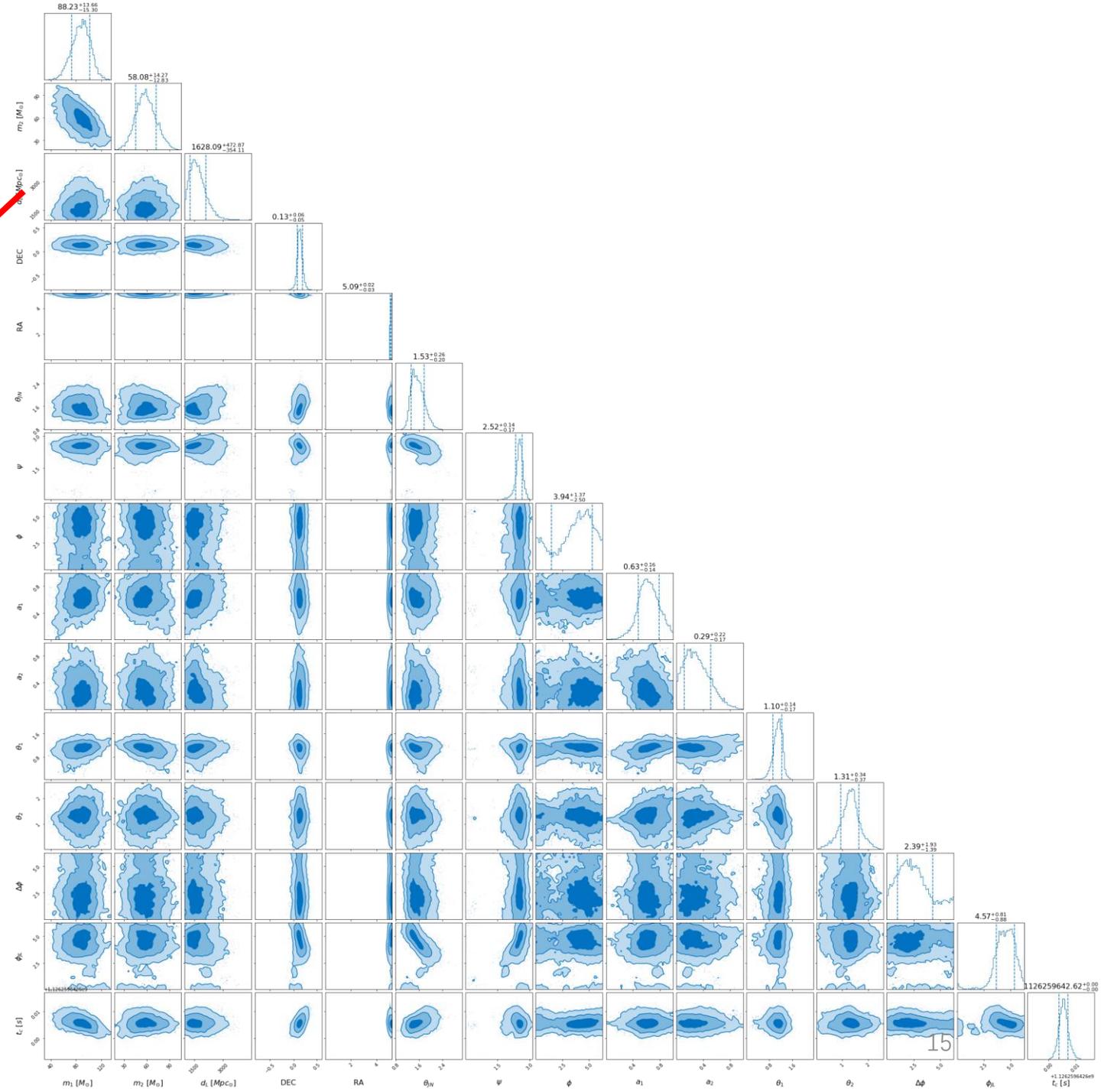
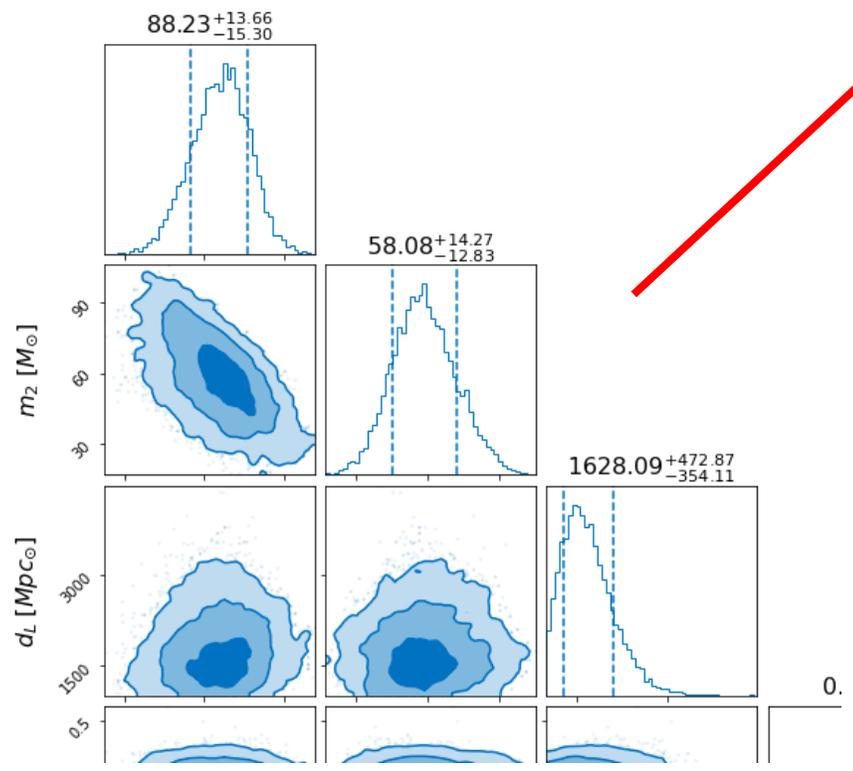


Fig.10 encounter on Bilby with spinning model

## Bias of BH encounter's parameters using BBH model for Bayesian Inference.

No.	$m_1(M_\odot)$			$m_2(M_\odot)$			$d_L(\text{Mpc})$			location(rad.)								
	ra	dec	psi	ra	dec	psi	ra	dec	psi	ra	dec	psi	ra	dec	psi			
2	75	76.23	88.23	75	66.5	58.08	15	2535	1628	0.42	4.87	5.09	-0.53	-1.13	0.13	0.92	1.74	2.52
3	100	85.15	117.2	50	72.65	88.34	10	2580	4338	5.83	4.86	1.26	-0.04	-0.96	1.13	0.86	0.87	0.75
6	141.18	101.68	138.76	8.82	92.53	33.77	1.5	3477	2750	5.83	1.34	1.77	-0.04	0.87	0.7	0.86	0.78	0.72

## Log Bayes factors

No.	Bayes factor		
	$\frac{\text{non-spinning}}{\text{null}}$	$\frac{\text{spinning}}{\text{null}}$	$\frac{\text{spinning}}{\text{non-spinning}}$
2	16.22+/-0.23	20.35+/-0.21	4.13
3	114.2+/-0.22	104.72+/-0.23	-9.48
6	26.69+/-0.21	25.35+/-0.21	-1.34

# Inject BBH using maximums of encounter's posterior

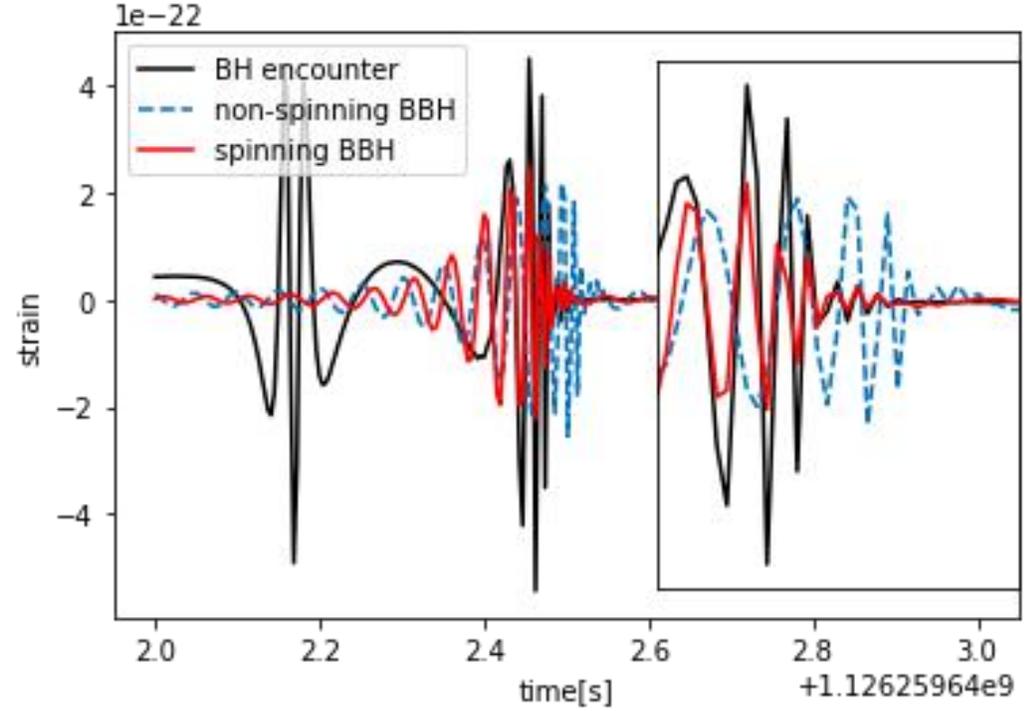
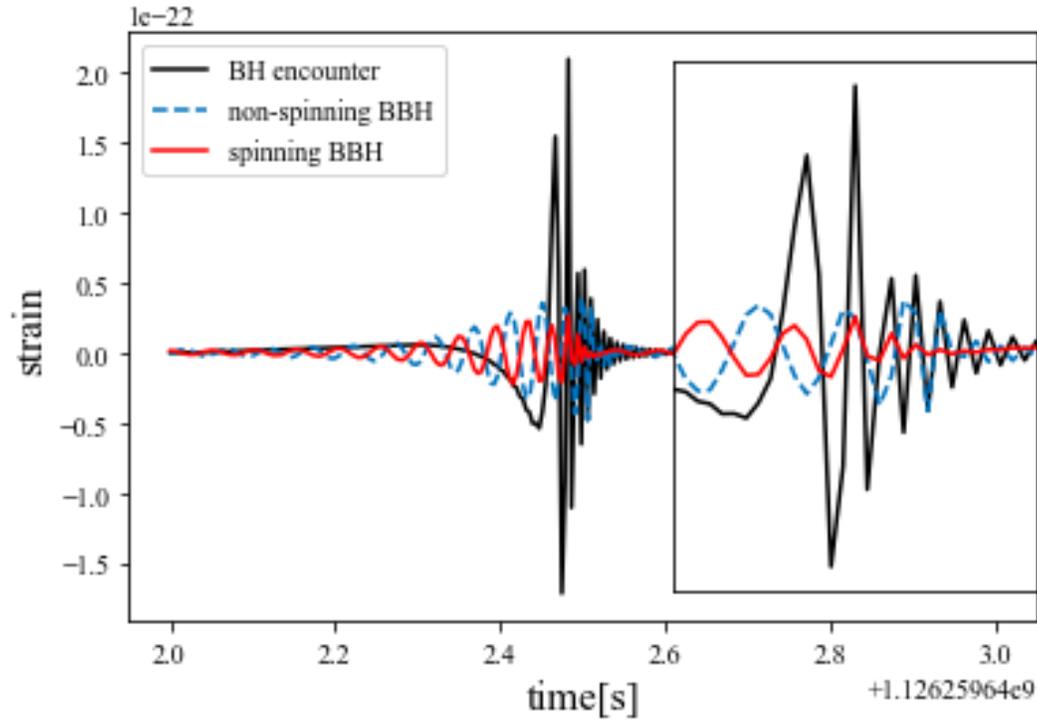


Fig.11 Signal No.2 and No.3 (q = 1, 2)

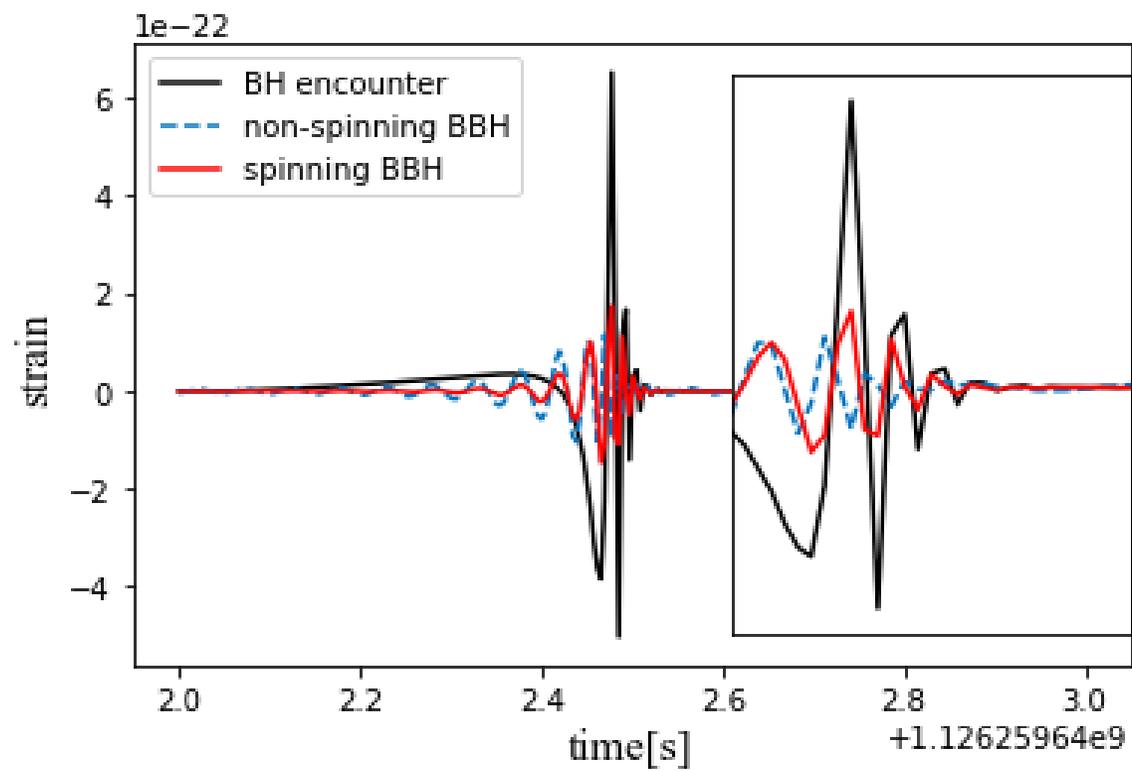


Fig.12 Signal No.6 ( $q = 16$ )

In the future...

IMRPhenomXHM model

# Appendix

## Bayesian inference

Sampler: Dynesty

Nsamples ~ 25000

Npoints: 1000

## Bilby prior

Parameter	min	max	units	prior
$m_{1,2}$	5	160	$M_{\odot}$	uniform
$d_L$	1000	5000	Mpc	uniform
$t_0$	0.15	0.35	seconds	uniform
ra	0	$2\pi$	rad.	uniform
dec	$-\pi/2$	$\pi/2$	rad.	cosine
$\Theta_{jn}$	0	$\pi$	rad.	sine
$\psi$	0	$\pi$	rad.	uniform
$\phi$	0	$2\pi$	rad.	uniform
spins	0	-	-	-
epoch	1126259642	GPS time	-	-
detector network	H1, L1, V1			

Parameter	min	max	units	prior
$m_{1,2}$	5	160	$M_{\odot}$	uniform
$d_L$	1000	5000	Mpc	uniform
$t_0$	-1	1	seconds	uniform
ra	0	$2\pi$	rad.	uniform
dec	$-\pi/2$	$\pi/2$	rad.	cosine
$\Theta_{jn}$	0	$\pi$	rad.	sine
$\psi$	0	$\pi$	rad.	uniform
$\phi$	0	$2\pi$	rad.	uniform
$a_{1,2}$	0	0.99	rad.	uniform
$\theta_{1,2}$	0	$\pi$	rad.	sine
$\Delta\phi$	0	$2\pi$	rad.	uniform
$\phi_{JL}$	0	$2\pi$	rad.	uniform
epoch	1126259642	GPS time	-	-
detector network	H1, L1, V1			

# Signal No.3 (q = 2)

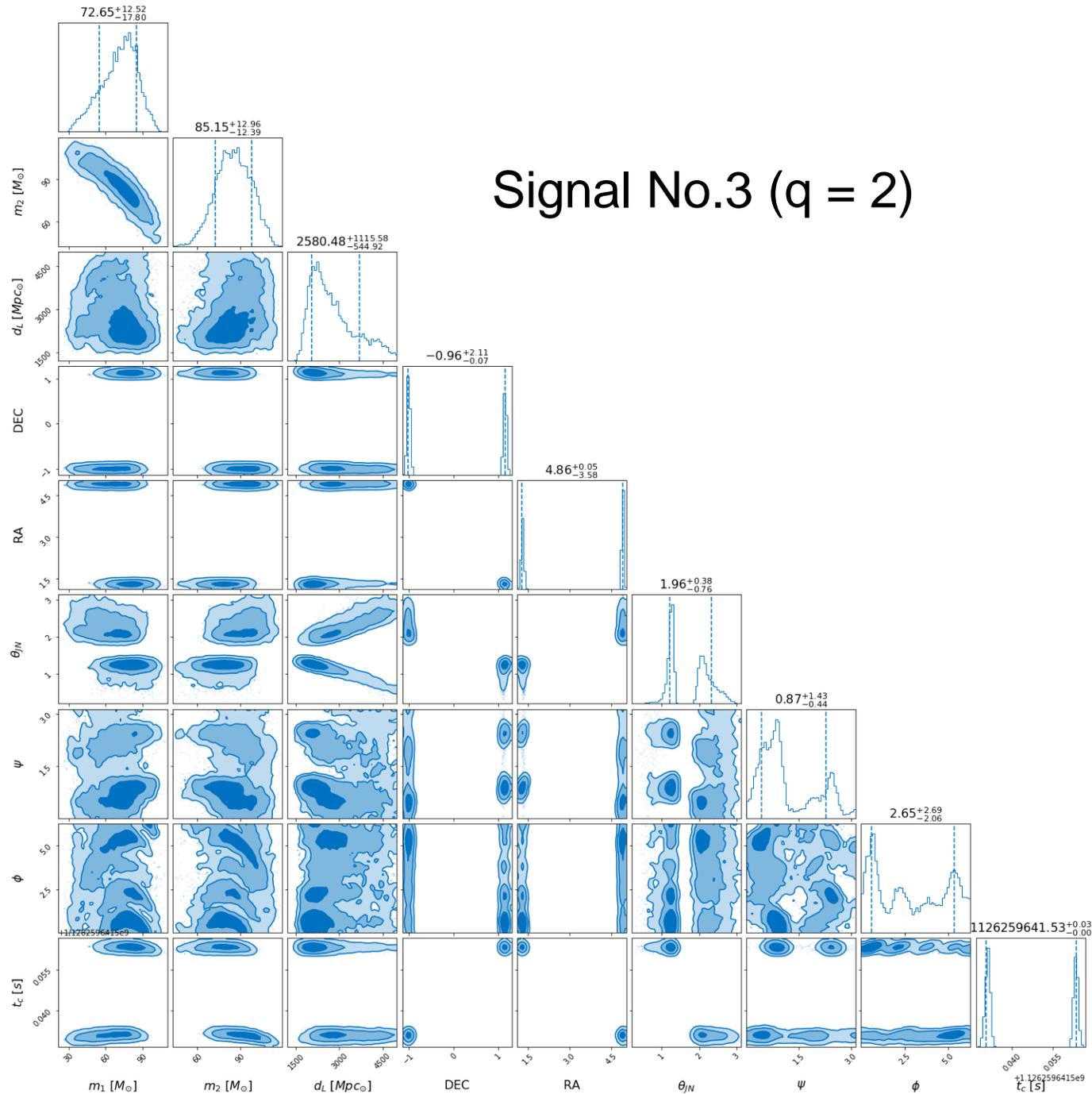


Fig.13 encounter using non-spinning model

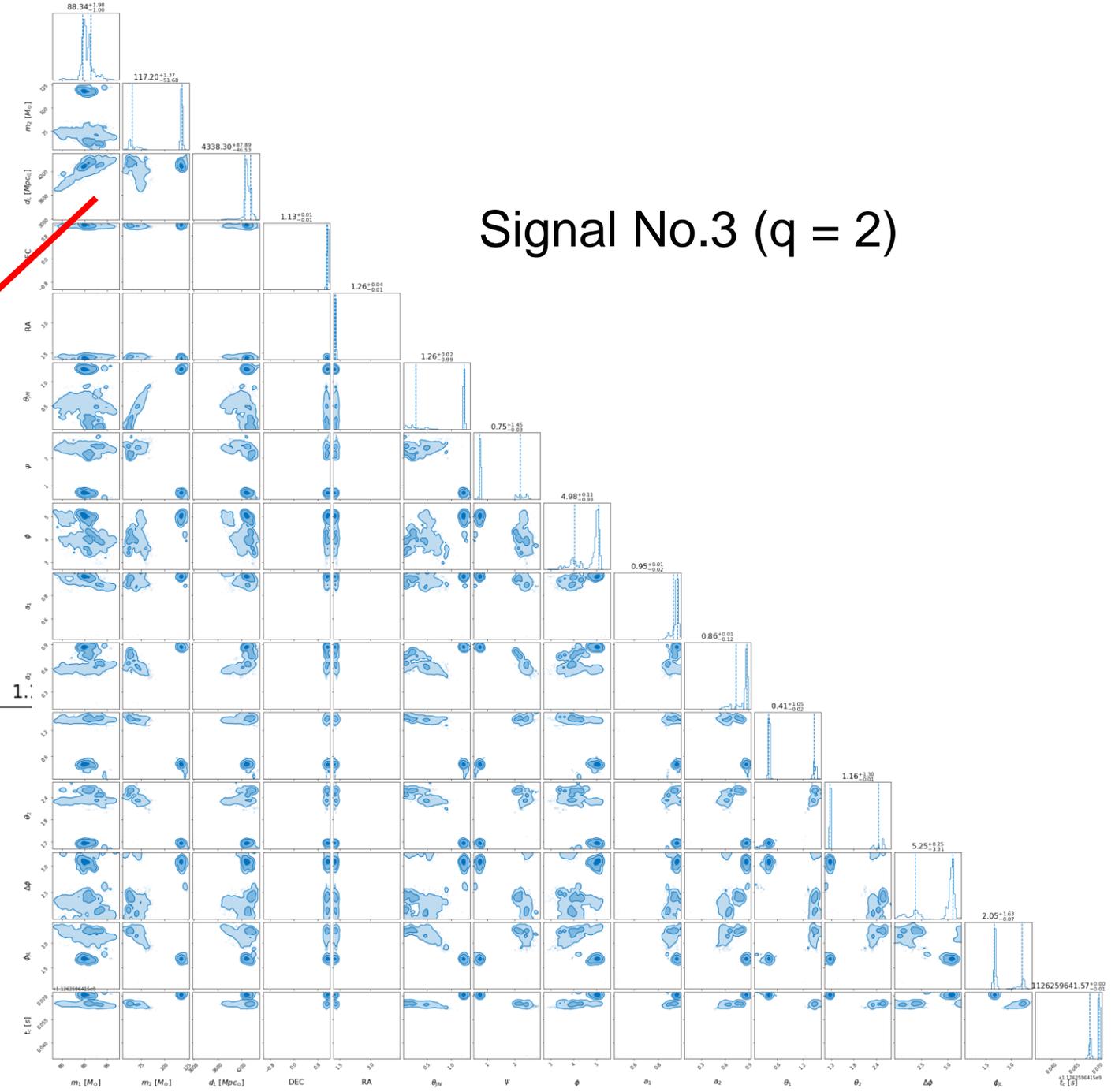
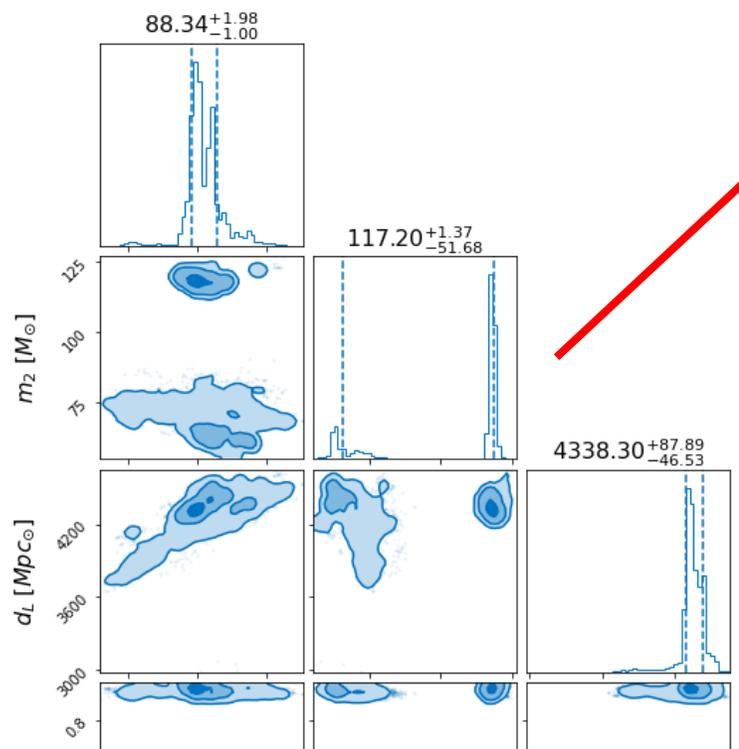


Fig.14 encounter using spinning model

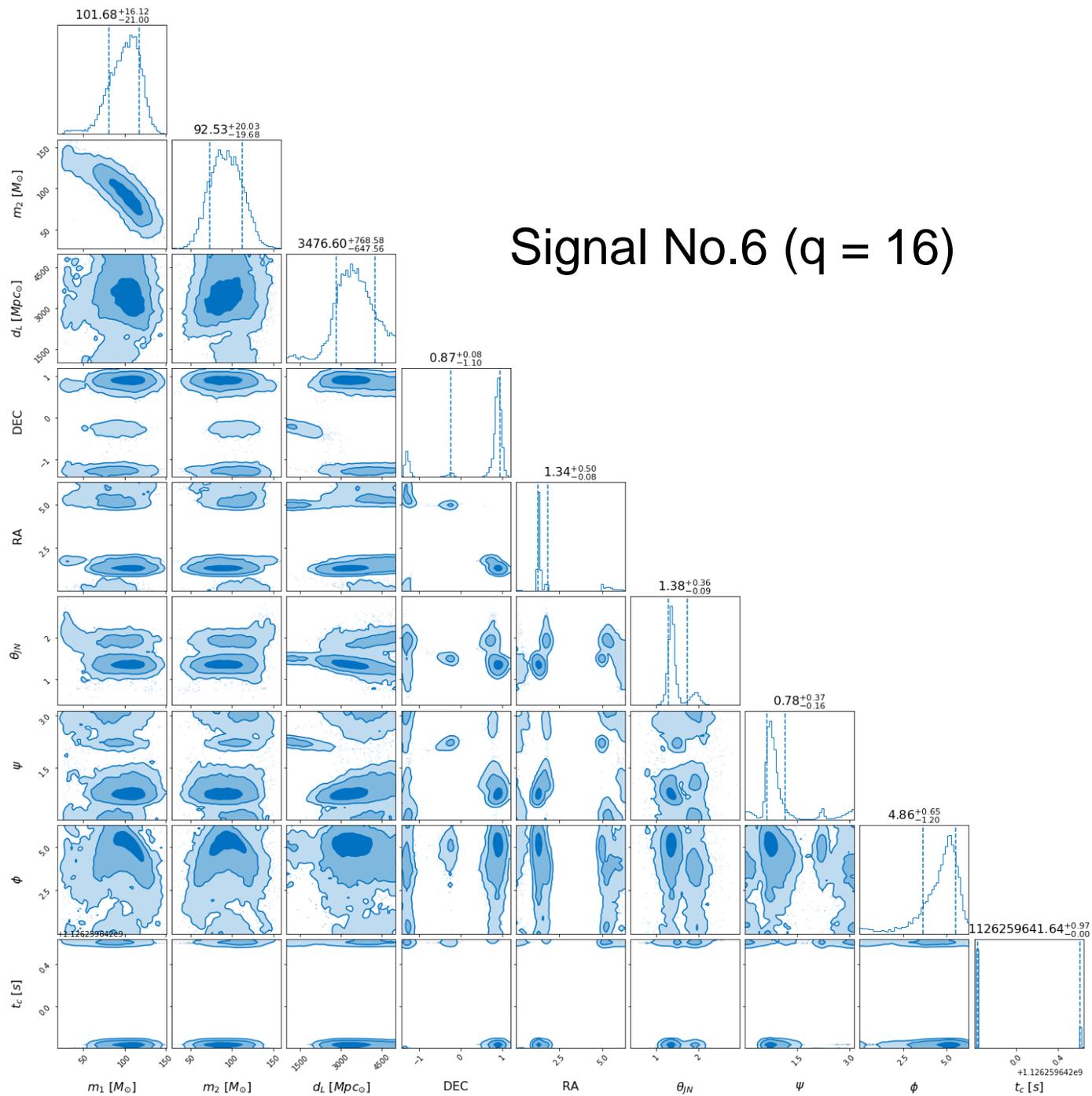
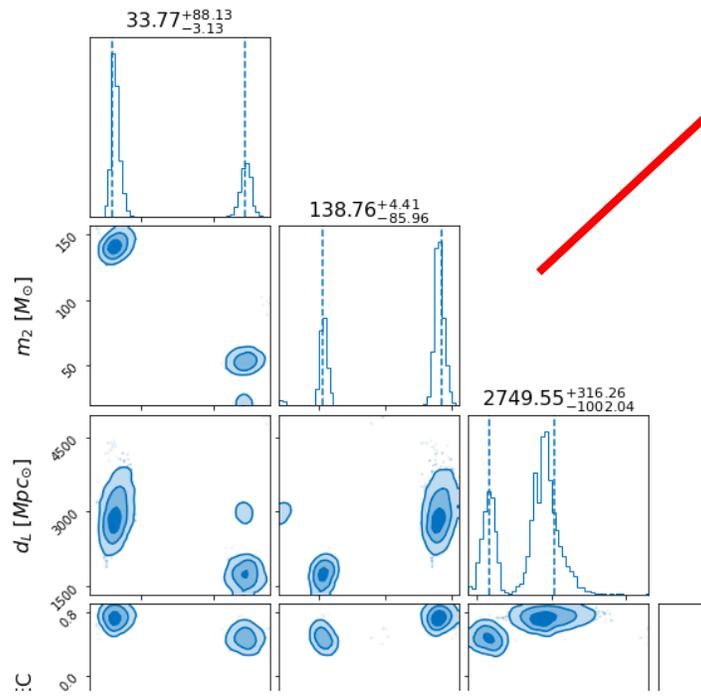


Fig.15 encounter using non-spinning model



Signal No.6 (q = 16)

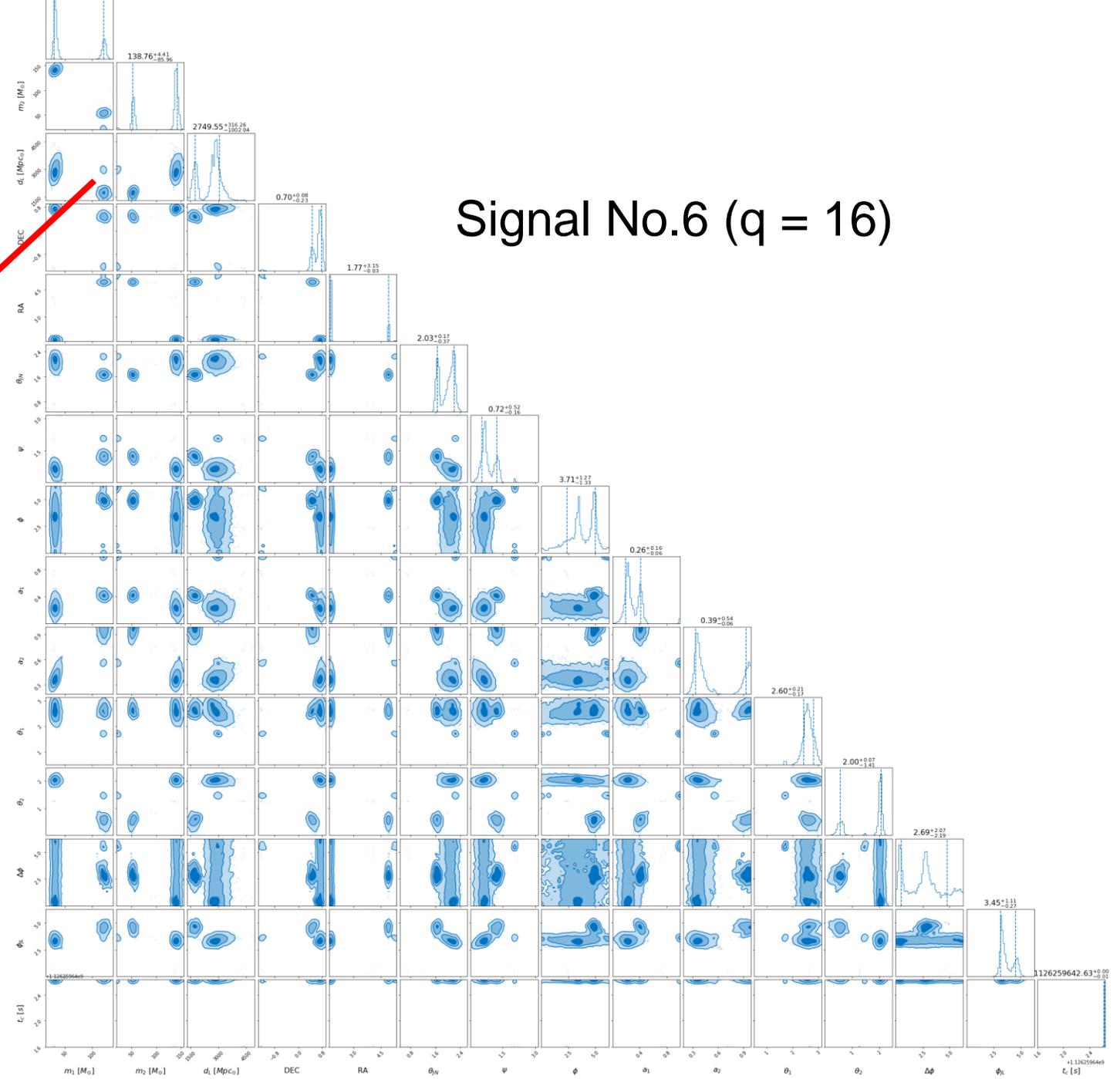


Fig.16 encounter using spinning model